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## (54) Pressure-charged engine systems

(57) Charge air for an engine (12) is compressed by a compressor (26) of a turbocharger, and supplied to the engine through first and second heat exchangers (44, 46), where it is cooled. The first heat exchanger (44) uses liquid coolant tapped off from the engine cooling circuit (36, 38, 41, 40) through a line (48), from a point downstream of the main radiator (36). The second heat exchanger (46) uses liquid coolant which has been cooled by a separate heat exchanger (56) to a temperature lower than the coolant in line 32.

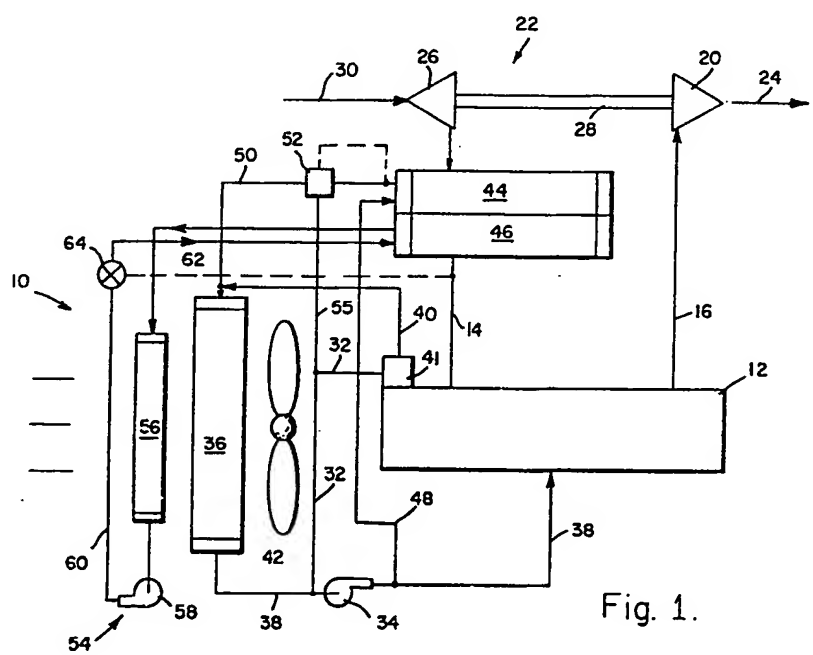


Fig. 1.

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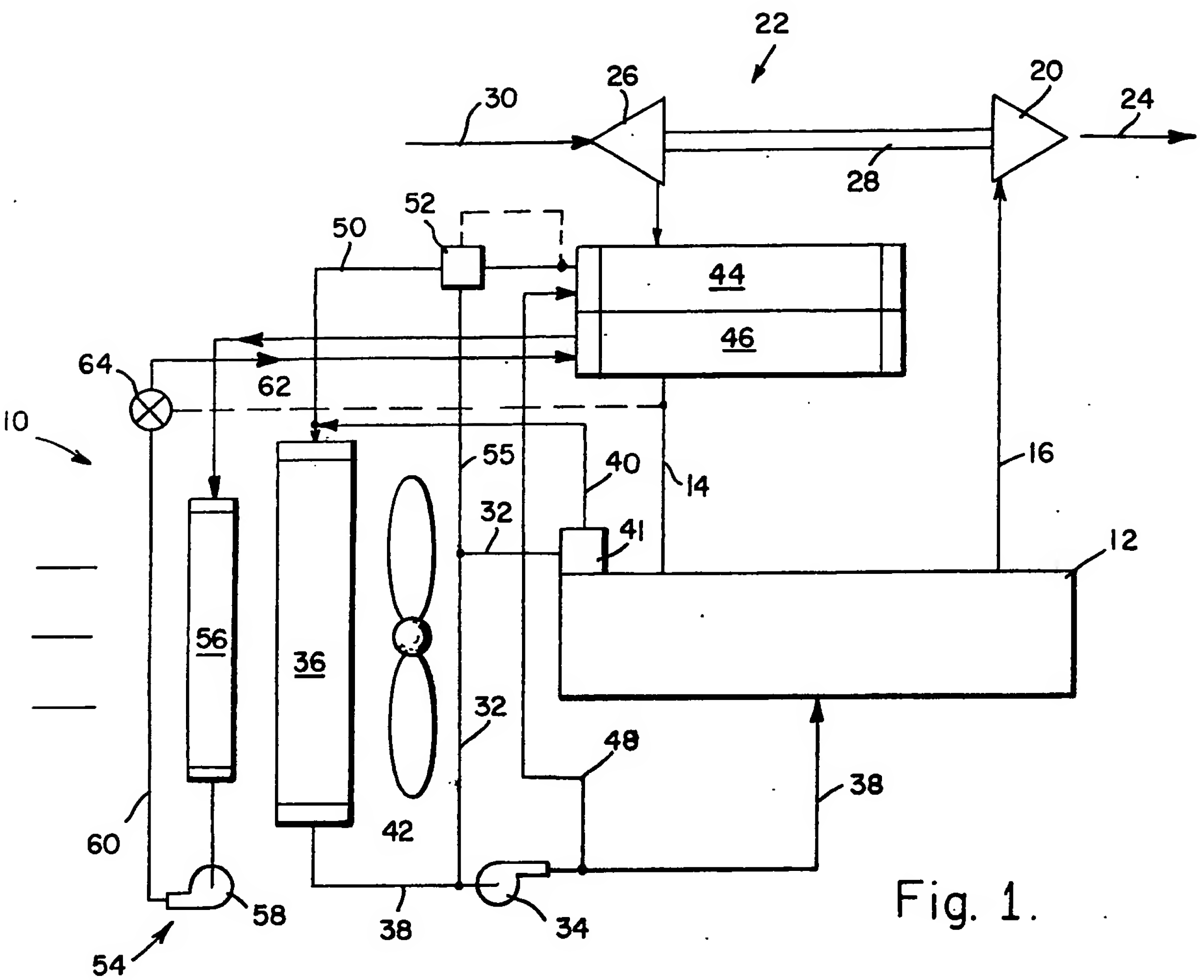


Fig. 1.

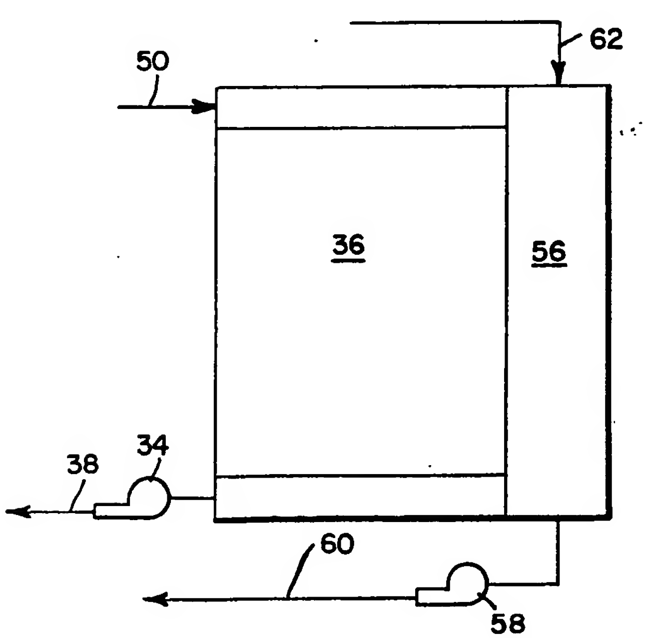


Fig. 2.

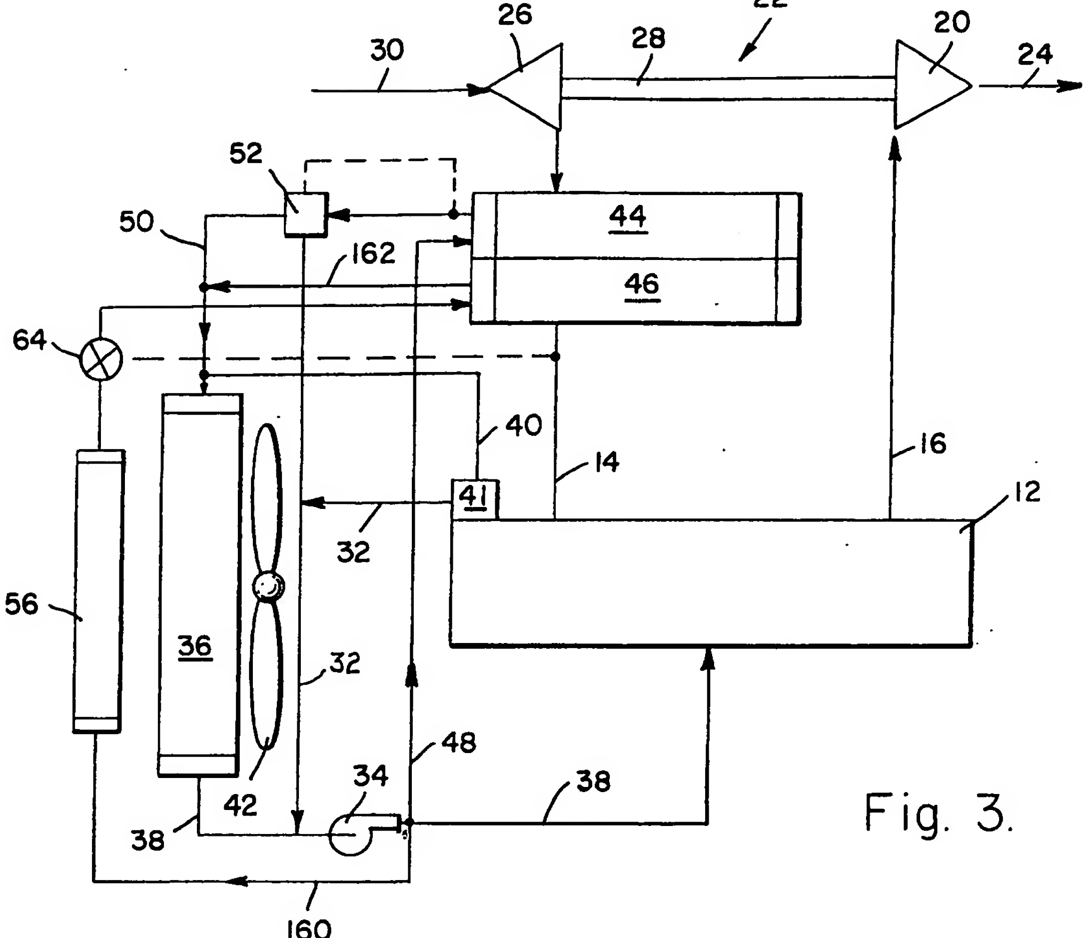

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Fig. 3.

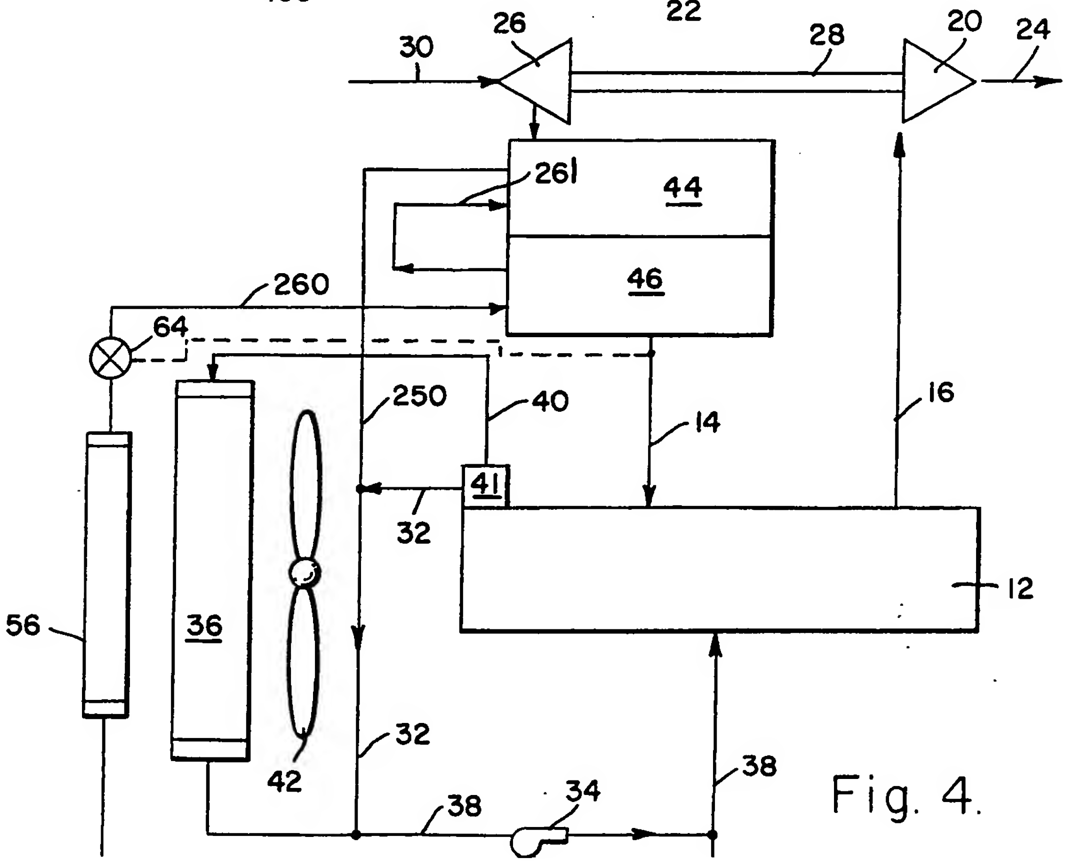

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Fig. 4.

SPECIFICATION

**Pressure-charged engine systems**

This invention relates to pressure-charged internal combustion engine systems, and more particularly to such systems in which the compressed charge air is cooled before being supplied to the engine, in order to increase its density and thereby increase the power and efficiency of the engine.

Most engines are liquid-cooled, and the engine cooling system is a convenient source of coolant for cooling the charge air. However, this coolant will be at a relatively high temperature, so that the amount of cooling of the charge air which can be obtained is limited. The present invention is concerned with arrangements which avoid this limitation.

According to one aspect of the present invention, a pressure-charged internal combustion engine system comprises a charge air compressor connected to supply charge air to an engine, the engine being coupled in a series loop with a radiator and means for circulating a liquid coolant around the loop to cool the engine, and the system also including first and second air-to-liquid heat exchangers coupled in series, in that order, in the path of the charge air between the charge air compressor and the engine, the first heat exchanger being coupled to receive, as liquid coolant, a portion of the liquid coolant flowing from the radiator towards the engine, and the second heat exchanger being coupled to receive a liquid coolant at a temperature lower than that of the coolant supplied to the first heat exchanger.

Such an arrangement should allow the charge air to be cooled to a reasonably low temperature, without being unduly complicated.

The liquid coolant for the second heat exchanger may circulate in a system which is separate from the engine cooling system and the first heat exchanger, and which contains its own heat exchanger for cooling the liquid coolant. Alternatively, the liquid coolant for the second heat exchanger may be taken from the engine cooling loop, downstream of the radiator, and then cooled further in its own cooling heat exchanger before being supplied to the second heat exchanger for cooling the charge air.

The compressed charge air is preferably supplied by an exhaust-driven turbocharger, although other pressure-charging arrangements are possible.

The invention also provides, according to a second aspect, a method of operating a pressure-charged internal combustion engine system, in which method a liquid coolant is circulated around a loop containing the engine, and is cooled in its passage around the loop before returning to the engine, and compressed charge air is cooled, in two stages, by heat transfer to a liquid coolant or coolants, and is then supplied to the engine, the liquid coolant for the first stage of charge air before returning to the engine, and the liquid coolant supplied for the second stage of charge air cooling is at a lower temperature than that supplied for the first stage of charge air cooling.

The invention may be carried into practice in various ways, but various specific embodiments will now be described by way of example, with reference to the accompanying drawings, of which:

Figure 1 is a schematic diagram illustrating a turbocharged engine system including a cooling system embodying the invention;

Figure 2 is a schematic diagram illustrating one possible arrangement of heat exchangers for the system of Figure 1; and

Figures 3 and 4 are schematic diagrams, similar to Figure 1, showing two further turbocharged engine systems embodying the invention.

A turbocharged engine system 10 is illustrated schematically in Figure 1, and comprises an engine 12 having an air intake 14 and an exhaust gas outlet 16. Exhaust gases leaving the engine 12 via the exhaust gas outlet 16 are supplied to a turbine 20 of a turbocharger 22. The exhaust gases drive the turbine 20 before exiting to atmosphere via an exhaust conduit 24. The rotating turbine 20 drives a compressor impeller 26 mounted on a shaft 28 common to the turbine 20. The rotating compressor impeller 26 draws in ambient air via an intake 30, and compresses the air for supply to the engine 12 via the engine air intake 14.

In an alternative arrangement, compressed air may be supplied to the engine intake by other means, such as a mechanically driven supercharger.

During operation, the engine 12 drives a pump 34 which pumps liquid coolant, usually a mixture of chemicals and water, from a radiator 36 to the engine 12 through a conduit 38. The coolant circulates through the engine to absorb heat generated by the engine, and returns to the radiator 36 through a return conduit 40. The collected heat is transferred to the ambient air by the radiator 36. A cooling fan 42 may be provided for forcing ambient air through the radiator 36 to increase the cooling capacity of the radiator; this fan 42 may be driven by a hydraulic, pneumatic, electrical, or shaft drive or the like. The temperature and flow rate of the liquid coolant circulating through the conduits 38 and 40 is controlled by a thermostatic control valve 41 mounted in the conduit 40 and arranged, if the coolant temperature is below a certain value, to bypass a portion of the coolant around the radiator 36 through a bypass conduit 32 coupled to the intake side of the circulation pump 34.

The charge air supplied from the compressor 26 passes in turn through first and second charge air heat exchangers 44 and 46, before reaching the engine 12. These charge air heat exchangers 44 and 46 each comprise an air-to-liquid heat exchanger, and may be combined into a single

heated, compressed charge air is passed through the first heat exchanger 44 for first stage cooling of the air to a reduced temperature level. The partially cooled charge air is then passed through the second charge air heat exchanger 46 for second stage cooling of the charge air prior to supply to the engine 12. In this manner, the temperature of the charge air is substantially reduced, in two stages, to increase the density of the charge air supplied to the engine, and to reduce the thermal loading upon critical components of the engine. To achieve efficient cooling of the air, the liquid coolant supplied to the second heat exchanger 46 is somewhat cooler than the liquid coolant supplied to the first heat exchanger 44, as will now be described.

As shown in Figure 1, the first charge air heat exchanger 44 is coupled into the engine cooling system. More specifically, a conduit 48 is coupled to the discharge side of the circulation pump 34, and supplies liquid coolant which has been cooled in the radiator 36 to the first charge air heat exchanger 44. Heat from the charge air is absorbed by the liquid coolant within the heat exchanger 44, and the thus-warmed coolant is returned directly to the engine radiator 36 by means of a return conduit 50. Thus, the first heat exchanger 44 is coupled in parallel with the engine 12 for receiving a portion of the coolant flow delivered by the pump, and the engine 12 and heat exchanger 44 together are coupled in series with the radiator 46. For precise temperature control, the conduit 50 may include a proportioning flow valve 52 responsive to the temperature of the coolant passing through the conduit 50 to return a portion of the liquid coolant directly to the intake side of the circulation pump 34 via a conduit 55 connected to the radiator bypass conduit 32.

The liquid coolant supplied to the second stage charge air heat exchanger 46 flows in an independent circulation loop 54 including a cooling heat exchanger 56 and a circulation pump 58. In operation, the pump 58 draws coolant from the cooling heat exchanger 56 and pumps the coolant through the second heat exchanger 46 via supply and return conduits 60 and 62. In this manner, the liquid coolant circulated through the second heat exchanger 46 is substantially lower in temperature than the coolant circulated through the first heat exchanger 44, so that substantial second stage cooling of the charge air is obtained. Preferably, a flow control valve 64 is provided in the conduit 60 for controlling the coolant flow in dependence on the temperature of the charge air supplied to the engine.

The cooling heat exchanger 56 and the engine radiator 36 are arranged back-to-back in the example of Figure 1, so that the fan 42 acts to draw ambient air through both heat exchangers 56 and 36 for cooling of the liquid coolants in these heat exchangers. Alternatively, as illustrated in Figure 2, the heat exchangers 56 and 36 may be arranged side-by-side in a single packaged unit application. Thus, as shown in Figure 2, the radiator 36 and the low temperature heat exchanger 56 are arranged for parallel passage of ambient air for cooling of the respective liquid coolants circulated through these heat exchangers. In this manner, the fan 42 may be used to draw ambient air simultaneously across both heat exchangers 56 and 36 without having the dissipated heat load of either heat exchanger affect the efficiency or cooling capacity of the other heat exchanger.

In the engine system of Figure 3, components identical to components in the system of Figure 1 are identified by like reference numerals. In the arrangement of Figure 3, the second charge air heat exchanger 46 is provided with liquid coolant taken from the engine cooling system. That is, a portion of the liquid coolant delivered by the engine system circulation pump 34 is supplied to the cooling heat exchanger 56 via a conduit 160, and is cooled in the heat exchanger 56 to a temperature lower than the temperature of the coolant supplied to the first charge air heat exchanger 44 via the conduit 48. The low temperature coolant leaving the heat exchanger 56 is then supplied to the second charge air heat exchanger 46 for absorbing heat energy from the already partly cooled charge air. This liquid coolant leaves the second heat exchanger 46 via a return conduit 162 which is coupled to the return conduit 50 of the first charge air heat exchanger 44, so that the coolant returns to the radiator 36. With this construction, the cooling heat exchanger 56 and the second charge air heat exchanger 46 are integrated with the engine cooling system in series with the radiator 36 and in parallel with both the engine 12 and the first charge air heat exchanger 44.

Another embodiment of the invention is illustrated in Figure 4, where components identical to components in the embodiments of Figures 1 and 3 are indicated by like reference numerals. In this system, the engine system circulation pump 34 provides liquid coolant for supply to the engine via the conduit 38, and subsequent return to the radiator 36 via the return conduit 40. A portion of the liquid coolant discharged by the pump 34 is supplied to the cooling heat exchanger 56 via a conduit 260, so that this portion of the coolant is cooled to a relatively low temperature. The coolant leaving the cooling heat exchanger 56 is supplied via the conduit 260 to the second charge air heat exchanger 46 for substantial cooling of the charge air flowing to the engine 12. The thus partially-warmed liquid coolant is discharged from the second heat exchanger 46, and is supplied via a conduit 261 directly to the first charge air exchanger 44, where the partially -warmed coolant is warmed further by heat transfer from the charge air. The coolant is then returned to the intake side of the circulation pump 34 via a return conduit 250. Alternatively, if desired, the warm coolant leaving the first heat exchanger 44 can be circulated back to the radiator 36 as in the

CLAIMS

1. A pressure-charged internal combustion engine system, comprising a charge air compressor connected to supply charge air to an engine, the engine being coupled in a series loop with a radiator and means for circulating a liquid coolant around the loop to cool the engine, and the system also including first and second air-to-liquid heat exchangers coupled in series, in that order, in the path of the charge air between the charge air compressor and the engine, the first heat exchanger being coupled to receive, as liquid coolant, a portion of the liquid coolant flowing from the radiator towards the engine, and the second heat exchanger being coupled to receive a liquid coolant at a temperature lower than that of the coolant supplied to the first heat exchanger.

2. A system as claimed in Claim 1, in which the first heat exchanger is coupled to return its liquid coolant to the series loop, between the engine and the radiator, whereby the first heat exchanger and the engine are coupled in parallel in respect of the coolant flow.

3. A system as claimed in Claim 2, in which the coolant circulating means is connected in series with both the engine and the first heat exchanger.

4. A system as claimed in Claim 1 or Claim 2 or Claim 3, which includes a third, liquid-cooling heat exchanger, the cooled liquid delivery from the third heat exchanger being connected to supply the liquid coolant to the second heat exchanger.

5. A system as claimed in Claim 4, in which the second and third heat exchangers are coupled in a cooling circuit separate from the said series loop, which circuit also includes means for circulating the liquid coolant.

6. A system as claimed in Claim 4, in which the third heat exchanger is coupled to cool liquid coolant taken from the flow of coolant from the radiator towards the engine.

7. A system as claimed in Claim 6, in which the coolant circulating means is connected to circulate coolant from the radiator both through the engine and through the third and second heat exchangers.

8. A system as claimed in any of Claims 4 to 7, which includes means for directing a flow of cooling air in turn through the third heat exchanger and the radiator.

9. A system as claimed in any of Claims 4 to 7, which includes means for directing a flow of cooling air through the third heat exchanger and the radiator, with part of the air flow passing through the third heat exchanger and part through the radiator.

10. A system as claimed in any of the preceding claims, which also includes flow-regulating means coupled to control the flow of liquid coolant through the second heat exchanger, in dependence on the temperature of one of the fluid flows associated with the second heat exchanger.

11. A system as claimed in Claim 10, in which the flow-regulating means controls the said flow in dependence on the temperature of the charge air flowing from the second heat exchanger to the engine.

12. A system as claimed in any of the preceding claims, which also includes flow-regulating means coupled to control the flow of liquid coolant through the first heat exchanger, in dependence on the temperature of one of the fluid flows associated with the first heat exchanger.

13. A system as claimed in Claim 12, in which the flow-regulating means controls the said flow in dependence on the temperature of the charge air flowing from the first heat exchanger to the second heat exchanger.

14. A pressure-charged internal combustion engine system, substantially as herein described, with reference to any of Figures 1, 3 and 4, with or without the modification shown in Figure 2, of the accompanying drawings.

15. A cooling system for a charge air combustion engine, comprising a radiator mounted in series with the engine for circulation of a liquid coolant through said radiator and the engine for controlling the operating temperature of the engine; first and second charge air heat exchanger means for serial passage of charge air supplied to the engine; and means for circulating a liquid coolant having a first temperature level through said first heat exchanger means for first stage cooling of the charge air, and for circulating a liquid coolant having a second relatively lower temperature level through said second heat exchanger means for further and second stage cooling of the charge air.

16. A method of operating a pressure-charged internal combustion engine system, in which method a liquid coolant is circulated around a loop containing the engine, and is cooled in its passage around the loop before returning to the engine, and compressed charge air is cooled, in two stages, by heat transfer to a liquid coolant or coolants, and is then supplied to the engine, the liquid coolant for the first stage of charge air cooling being taken from the engine cooling loop, at a point where the coolant has been cooled before returning to the engine, and the liquid coolant supplied for the second stage of charge air cooling is at a lower temperature than that supplied for the first stage of charge air cooling.

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